SUMMARY REPORT

APOLLO SERVICE PROPULSION SYSTEM ROCKET ENGINE BIPROPELLANT VALVE IMPROVEMENT PROGRAM

Prepared Under
Contract NAS 9-8317

For

MANNED SPACECRAFT CENTER
National Aeronautics and Space Administration
Houston, Texas

Report NASA 108578 March 1971

AEROJET LIQUID ROCKET COMPANY

A DIVISION OF AEROJET-GENERAL

SACRAMENTO, CALIFORNIA

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I. INTRODUCTION

This report summarizes the work accomplished under Contract NAS 9-8317, the Apollo Service Propulsion System (SPS) Rocket Engine Bipropellant Valve Improvement Program.

Phase I of the program was directed toward the improvement of the Apollo SPS engine bipropellant valve. This phase started in July 1968 and ended in December 1969.

Phase II was concerned with Oxygen-Hydrogen technology. Two workhorse type valves were fabricated and tested with two types of seals at cryogenic temperatures. This phase started in July 1970 and ended in February 1971.

II. STUDY OBJECTIVES

The primary objective of Phase I was to improve upon the existing SPS bipropellant valve. A secondary objective was the publication of a valve design guide.

Phase II effort was directed toward Oxygen-Hydrogen technology with the objective of evaluating both static and dynamic valve seals at cryogenic temperatures.

III. RELATIONSHIPS TO OTHER NASA EFFORTS

The Phase I portion of the contract had a direct relationship with Contract NAS 9-150 under which the Service Module was procured. This relationship existed because the ultimate objective of the program was to provide an improved valve to replace the existing SPS valve. Consequently, much of the design criteria was based on previous SPS experience or requirements.

Phase II utilized remaining contract funding to develop Oxygen-Hydrogen technology. To obtain this technology, two propellant valves were designed and fabricated. These valves were designed with a dual objective: (1) to serve as a tool to evaluate seal configurations in laboratory type tests; and (2) to be capable of being used in hot fire tests in conjunction with the injector and combustion chamber developed under Contract NAS 9-8285.

IV. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The function of the SPS bipropellant valve is to control the flow of propellants [N_2O_4 and AeroZINE 50 (50/50 UDMH-Hydrazine)] to the engine. Because of the critical nature of the Apollo mission, the valve was designed with parallel and redundant features which resulted in the valve really being two valves in one assembly.

Each pair of fuel and oxidizer flow passages is controlled by a separate and independent pneumatic actuation system. Each flow passage has two ball valves, each of which has two seals.

The SPS valve has experienced two major problem areas. These are marginal life cycle characteristics, i.e., excessive leakage after cycling, and complicated assembly and repair procedures.

The primary objective of Phase I of the Contract NAS 9-8317 was to improve upon the undesirable features of the existing valve design. Phase I started during the first week of July 1968.

Related experience was reviewed and tradeoff studies were conducted to establish the basic valve concept. The selected concept retained the basic SPS dual propellant passages with redundant dual seal ball valves, but departed significantly from the SPS in other design areas: (1) the valve assembly was completely modular, i.e., individual, interchangeable ball and seal assemblies, housings, actuators, and actuation systems for ease of maintenance; (2) the ball seals were lifted free of the ball in the first few degrees of motion to reduce the wiping action and improve cycle life; (3) the drive mechanism incorporated idler gears to ensure that the bores of the fuel and oxidizer balls were parallel to the housing bores when in the full open position; and (4) the return spring of the actuators was positioned external to the actuation cavity. The pneumatic actuation control was retained, although it was recognized that an electrical system would offer some advantages. Figure 1 shows the basic design concept.

First priority was assigned to the valve cartridge, i.e., the module which contains one ball, liftoff cams, and the upstream and downstream seals. As soon as the drawing status permitted a good approximation of the final configuration, a test assembly composed of obsolete SPS components was fabricated to test the feasibility of the concept. The results of these tests showed excellent seal life and unsatisfactory cam cycle life. Consequently, the prototype design was modified to increase the cam bearing width.

Prototype cartridge dry cycle testing started during the latter part of May 1969. The results of these tests demonstrated the concept to be completely satisfactory.

Assembly of the two-bore valve started in September 1969. This assembly consisted of one fuel bore and one oxidizer bore, i.e., one half of a prototype design. The results indicated that although some minor problems were yet to be solved, the valve demonstrated a definite potential for improvement over the existing SPS valve design, and further, a cycle life of 20,000 cycles with an attendant maximum leakage rate of approximately 50scc/hr could be realized.

Phase II, the cryogenic propellant portion of the program, started in June 1970. The objective of this program was to support related injector and chamber studies being conducted on another NASA sponsored contract at ALRC (Contract NAS 9-8285).

Two workhorse type valves were designed and fabricated. The valves were designed with a dual objective: (1) to have the capability of being test fired with the injector chamber combination available from NAS 9-8285; and (2) to have enough design flexibility to support laboratory seal testing. Consequently, the valves were overdesigned in that wide allowance was made to provide stock to machine grooves for various types of seals.

The initial study effort was directed toward a bipropellant valve design. However, after a review of potential engine configurations and available bipropellant valve designs, it was decided that a single valve concept would be more appropriate. A single valve offers more versatility with respect to lead-lag, mixture ratio control, and engine interface.

The preferred valve concept selected was a pneumatically actuated, angled poppet valve. The poppet configuration was chosen because of its high cycle life, minimum seal wear, and adaptability to size requirements. A pneumatic actuation system was selected over hydraulic and electric systems because of intended test stand usage. This actuation method affords a fail-safe capability, ability to vary valve response time without redesign, and to minimize the temperature effect on the actuation media. See Figure 2.

The primary objective of the test program was to evaluate the cryogenic performance of the polymeric dynamic shaft and piston seals and the poppet seal material. In addition, K_w versus valve position, ΔP at the design flowrate, and minimum achievable poppet travel time were determined.

The valve configuration for the first test series of 10,000 cycles was with RACO shaft and piston seals and the Kel-F molded poppet. An additional 10,000 cycle test was conducted with Delta dynamic seals and a partially encapsulated Teflon poppet. Primary design criteria and min/max leakage data from the test series are as follows:

Leakage Rate, SCC/HR GHe

	30 Psig		700 Psig	
	Min.	Max.	Min.	Max.
Actuator Piston Seals				
RACO	0	8,010	6,888	882,000
Delta	0	30	0	48,000
Rear Shaft Seal				
RACO	0	2,244	960	184,000
Delta	0	125	0	14,400
Front Shaft Seal (Toward Poppet)				
RACO	0	12,000	0	96,000
Delta	0	45	90	4,002
Poppet				
Kel-F	0	0	0	0
Teflon	0	90,000	0	10,410

NOTE: The above data are the minimum and maximum leakage rates noted throughout each of the 10,000 LN_2 cycle tests.

A minimum cycle life of 10,000 cycles at liquid nitrogen temperature was desired with leakage rates within the design criteria. The Kel-F poppet configuration achieved this goal; however, neither the RACO nor Delta dynamic seals remained within the design limits at low temperature. During the low pressure leakage tests, 30 psig GHe, the maximum Delta seal leakage was 125 scc/hr as compared to 2,244 scc/hr with a RACO seal in the same location. The maximum Delta seal leakage at the higher test pressure, 700 psig, GHe, was 48,000 scc/hr as compared to 882,000 scc/hr with a RACO seal. Dynamic seal leakage, in the RACO and Delta configurations, is attributed to seal shrinkage away from the sealing surface. This is confirmed by the leakage rates being within limits at ambient temperature both before the start of the 10,000 LN_2 cycles and at the conclusion. Indications are that the Delta dynamic seals are superior to RACO seals in cryogenic temperature applications; however, further effort would be required to verify that the seals could be brought within acceptable leakage limitations.

V. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

PHASE I

The basic output of this contract was the design of an Apollo SPS bipropellant valve with parallel redundant design features for high reliability.

The significant design features of this component are:

A. Modular construction
B. Cam actuated lift-off seals
C. Gear train drive

Tests of the valve demonstrated a significant improvement in both cycle life and leakage rates, e.g., after 20,000 N_2O_4 cycles, leakage rates of GN_2 at 175 psig were 100 cc/hr on the upstream seal and 0 in the downstream seal.

V, Basic Data Generated and Significant Results

PHASE II

During Phase II, two workhorse propellant valves were fabricated and two types of poppet materials and two dynamic seal configurations were tested at cryogenic temperatures for 10,000 cycles. The results of these tests constituted the basic data generated.

The results showed that leakage past the shaft and piston seals (RACO and Delta) were excessive for flight applications although the Delta configuration was superior to the RACO. (800,000 vs. 50,000 scc/hr GHe at 700 psig).

The Kel-F compression-moulded poppet did not leak during any portion of the test program; however, the Teflon poppet configuration would not be adequate in this application because of seat/poppet loading due to material cold flow.

VI. LIMITATIONS

PHASE I

Before the design developed during Phase I of the contract could be incorporated in the SPS engine, it would, of course, have to be subjected to a complete qualification test series which would include a number of conditions not evaluated in this program, e.g., high and low temperature, vibration, shock, etc. In addition, some work is also required in the area of assembly and cam run-in procedures and/or lubrication, especially in the fuel circuit.

VI. Limitations (continued)

PHASE II

There are no limitations with respect to the comparative results obtained on the leakage rates of the types of seals tested. In the event additional testing is conducted, the most promising candidates will be tested in their intended propellant rather than the -290°F nitrogen used in testing.

VII. IMPLICATIONS OF RESEARCH

PHASE I

Improved leakage rates and cycle life could be obtained for the SPS bipropellant valve.

The inherent susceptability to damage of conventional ball seals due to wiping action and contamination can be materially reduced by lifting the seals off the ball surface with cams.

PHASE II

The use of polymeric poppet seals for cryogenic service is well within existing state-of-the-art.

Dynamic seals for cryogenic service continue to be a problem although the Delta configuration showed promise.

VIII. SUGGESTED ADDITIONAL RESEARCH

PHASE I

No basic research, the results of which would be applicable to all designs, is apparent. Additional effort which would relate to the design developed under the auspices of this contract include:

a. A series of tests to establish seal life with respect to cam lift-off angle. The cams developed under this contract lifted the seals free of the ball in the first 6° of motion. This angle was arbitrary and it is entirely possible that the cam angle could be increased with no significant decrease in seal life. Any increase in the allowable cam angle will lower the stress level within the cams.

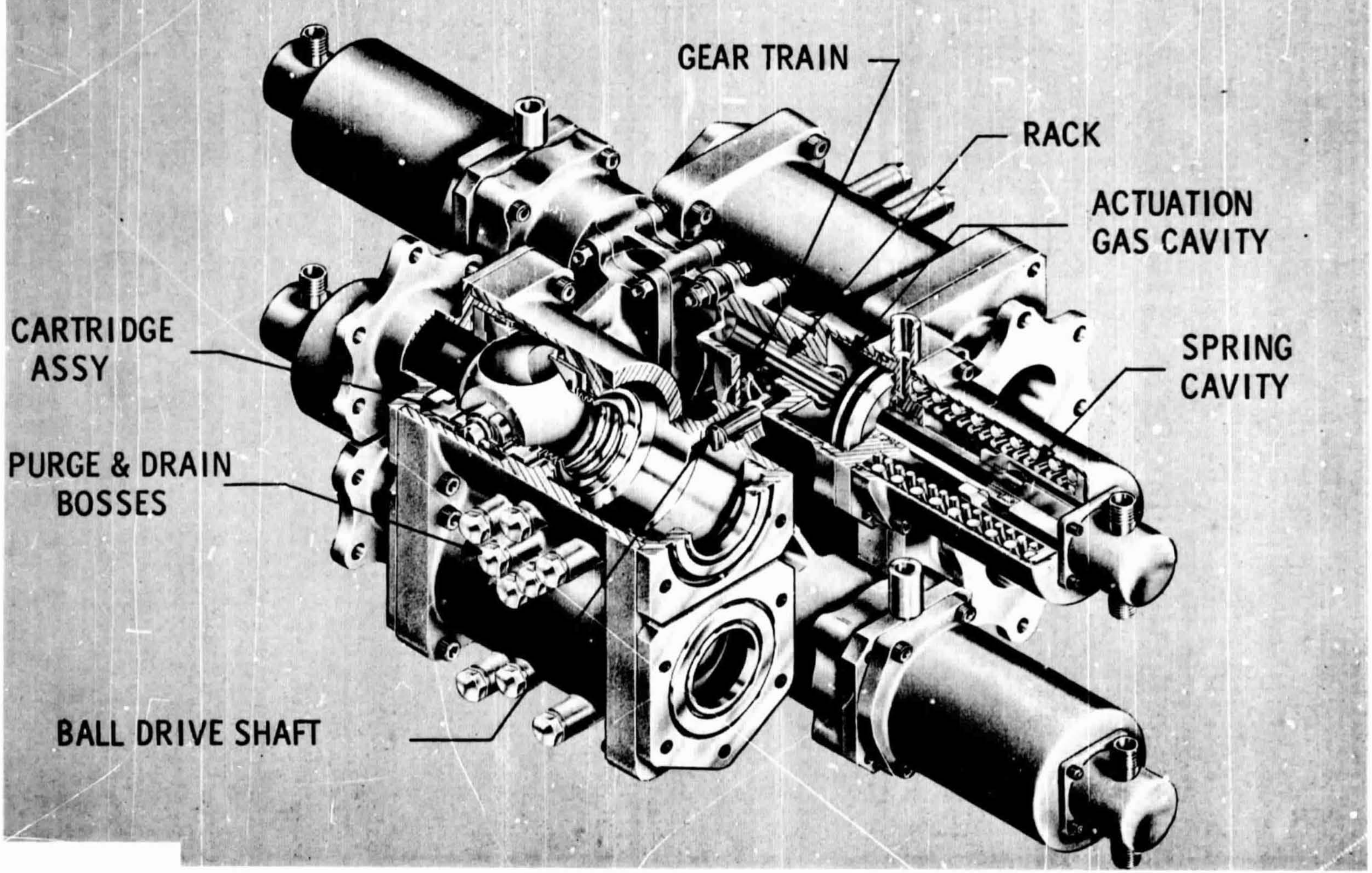
b. A test program with the objective of developing cam wear-in procedures and/or lubrication.

PHASE II

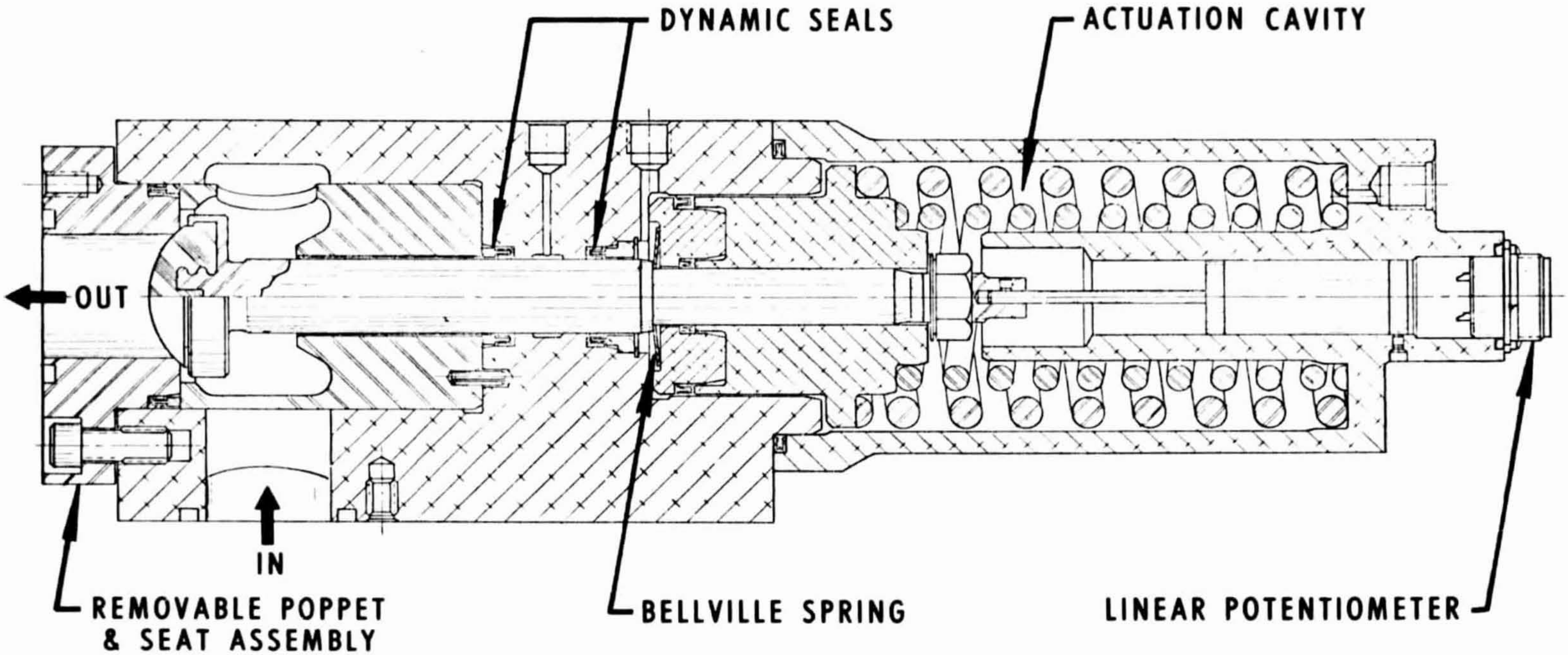
Additional data should be obtained on the molded Kel-F poppet and the method of seat loading with Belleville spring washers. Also to be determined would be the minimum load required to effect an adequate seal and load variation, if any, with increasing cycles and low temperatures. Additional testing should also be conducted to determine the life cycle of the Kel-F poppet at cryogenic temperatures. An upper limit in excess of 100,000 cycles does not appear unreasonable from the available test data.

The poppet shaft and actuator piston Delta seals should be evaluated further. Prior to this evaluation, the design criteria for each seal application would be analyzed with respect to seal material, surface finishes of mating parts, amount of shrinkage at cryogenic temperature, velocity of moving parts, amount of load required (axial and radial) to effect a good seal, and seal material hardness at low temperature. The edge angle of the Delta seal assembly would be changed accordingly to compensate for anticipated material property changes encountered at cryogenic temperatures.

SPS-VIP VALVE BODY



AJ-8 WORKHORSE VALVE ASSEMBLY



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